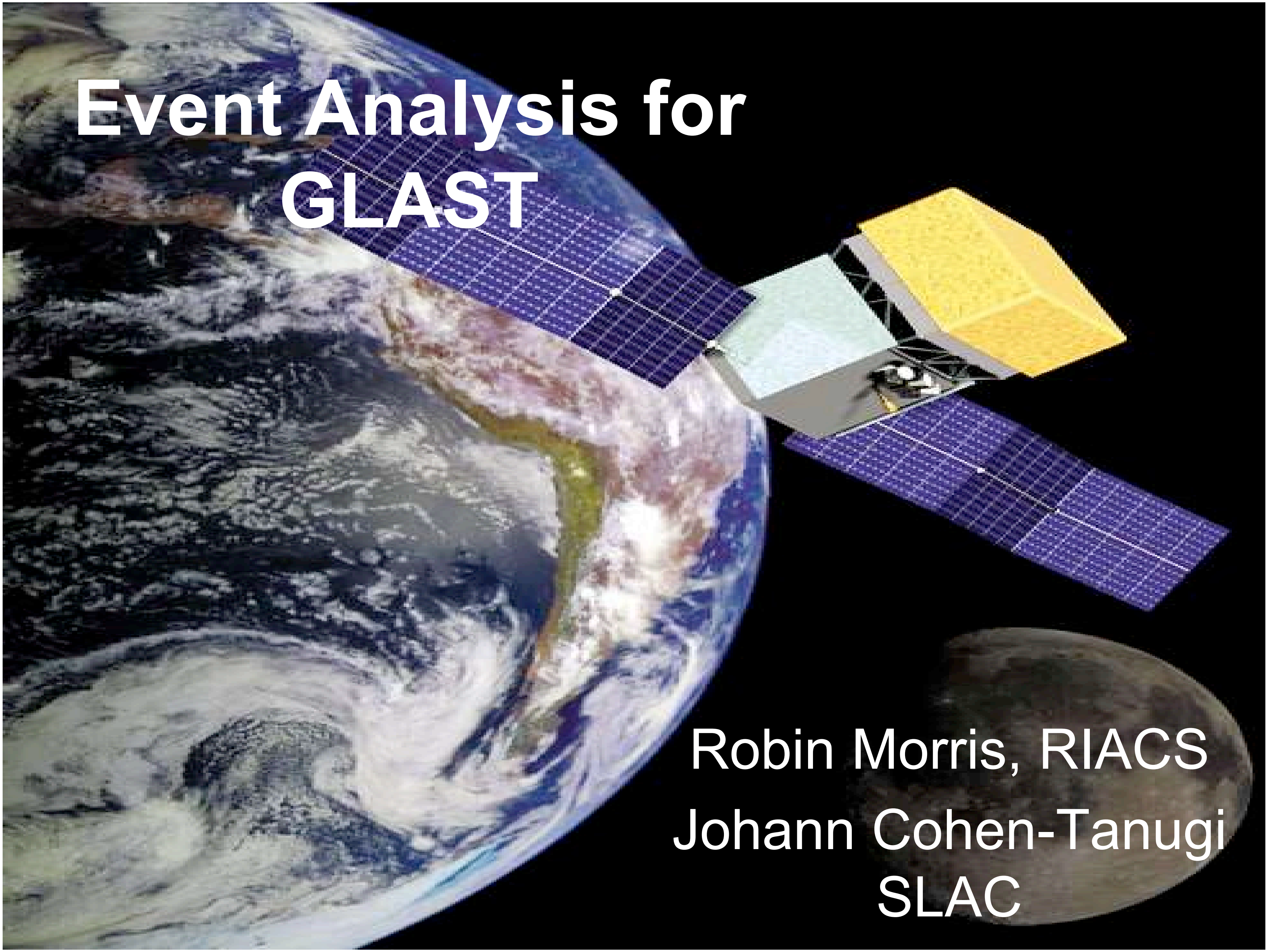
Event Analysis for GLAST



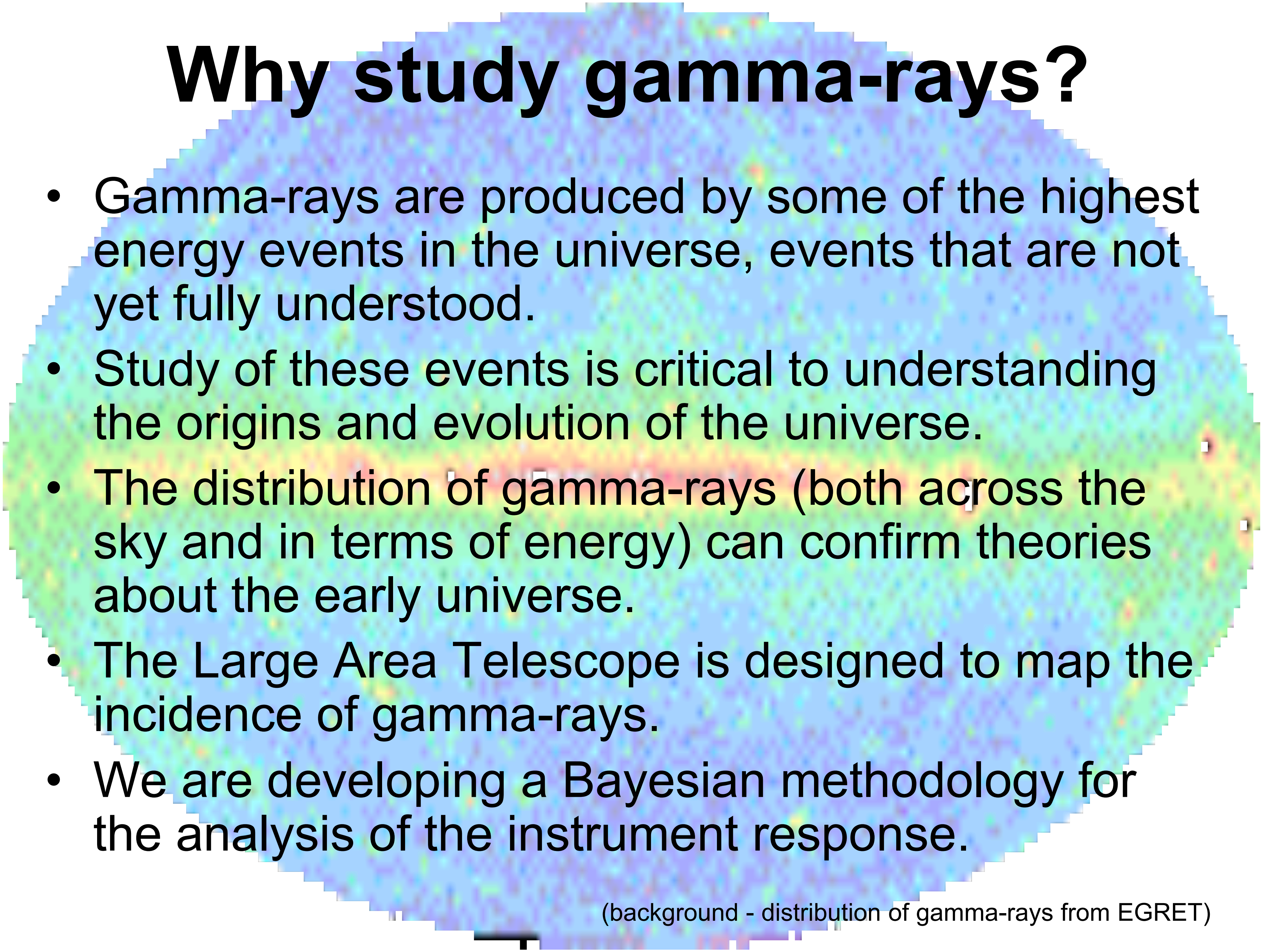
Robin Morris, RIACS

Johann Cohen-Tanugi

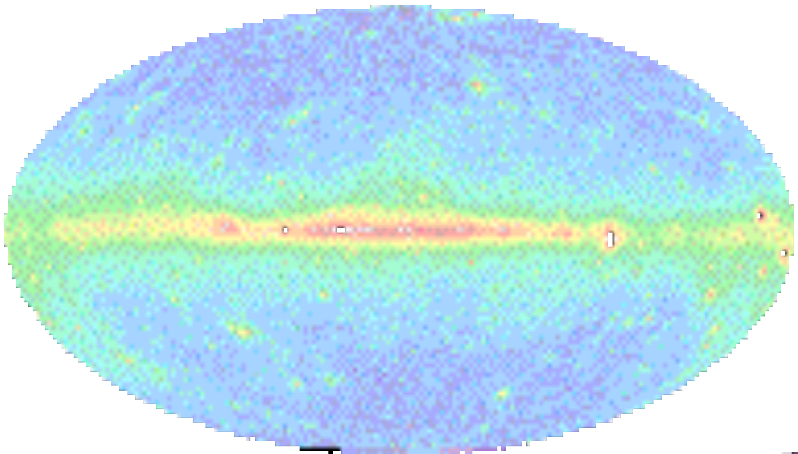
SLAC

Why study gamma-rays?

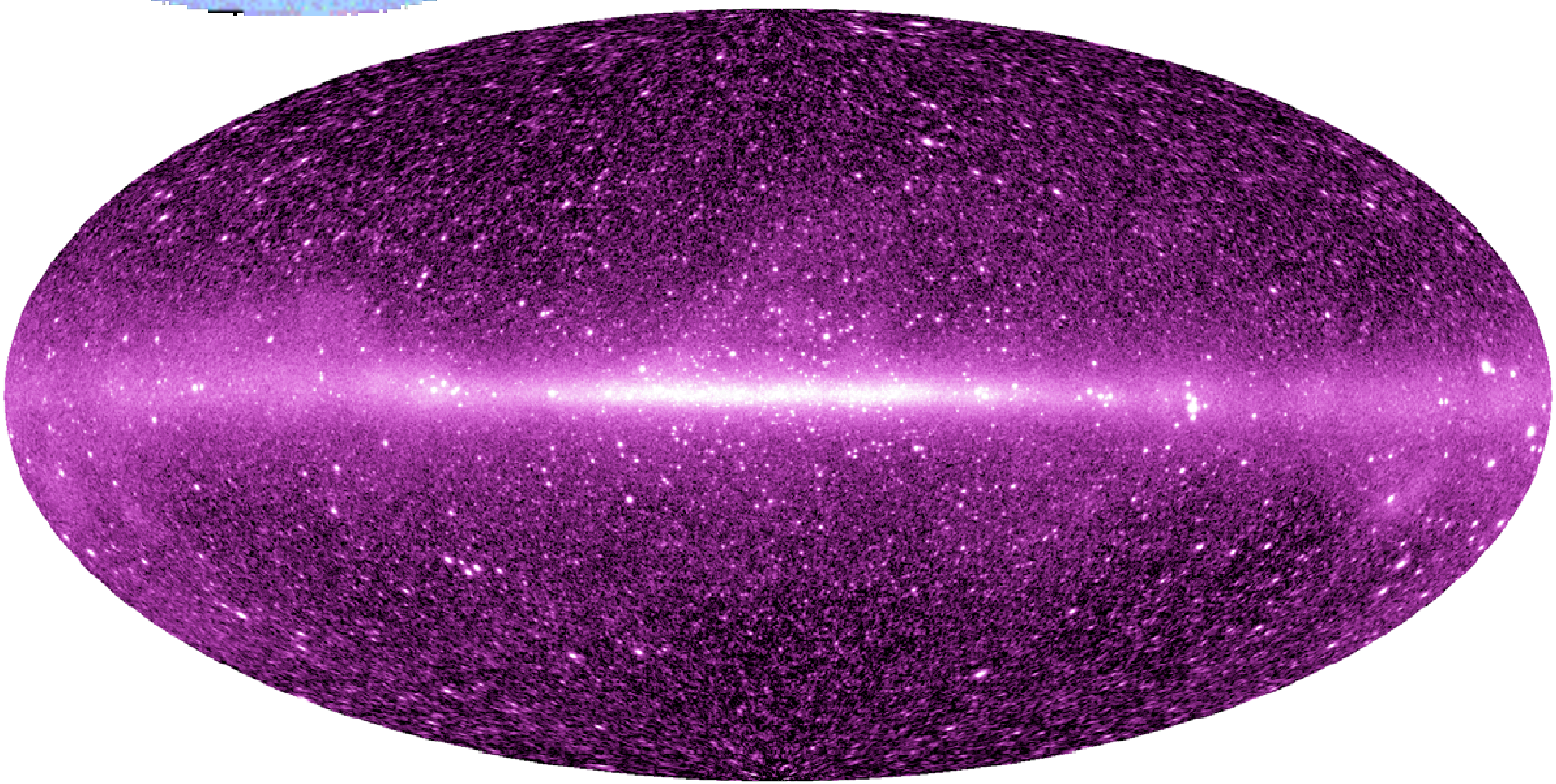
- Gamma-rays are produced by some of the highest energy events in the universe, events that are not yet fully understood.
- Study of these events is critical to understanding the origins and evolution of the universe.
- The distribution of gamma-rays (both across the sky and in terms of energy) can confirm theories about the early universe.
- The Large Area Telescope is designed to map the incidence of gamma-rays.
- We are developing a Bayesian methodology for the analysis of the instrument response.



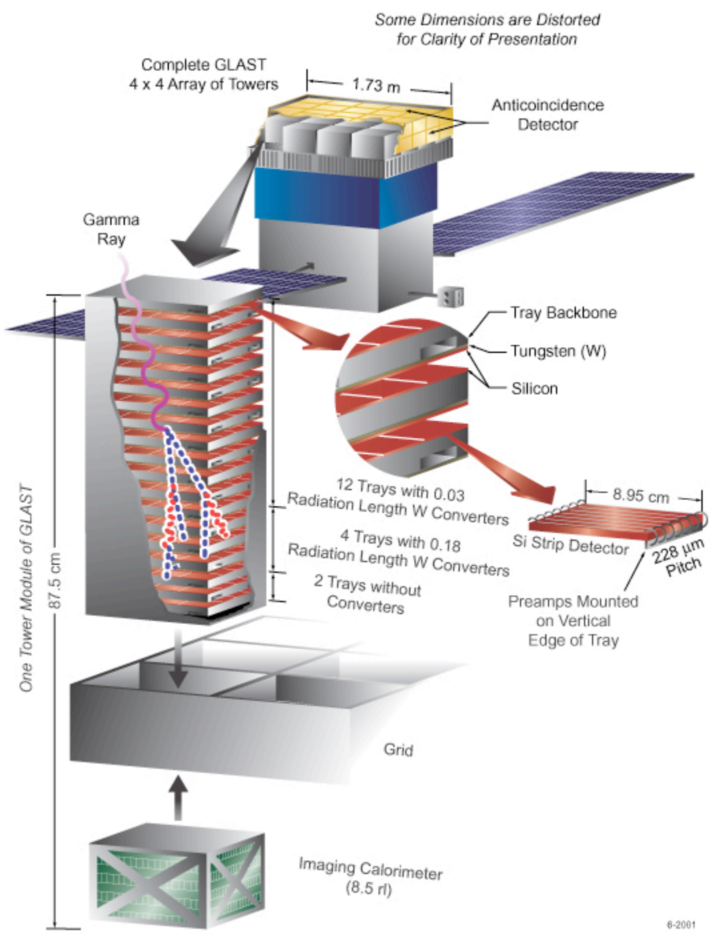
(background - distribution of gamma-rays from EGRET)



Expected improvement in resolution from EGRET to GLAST



The Large Area Telescope (LAT)

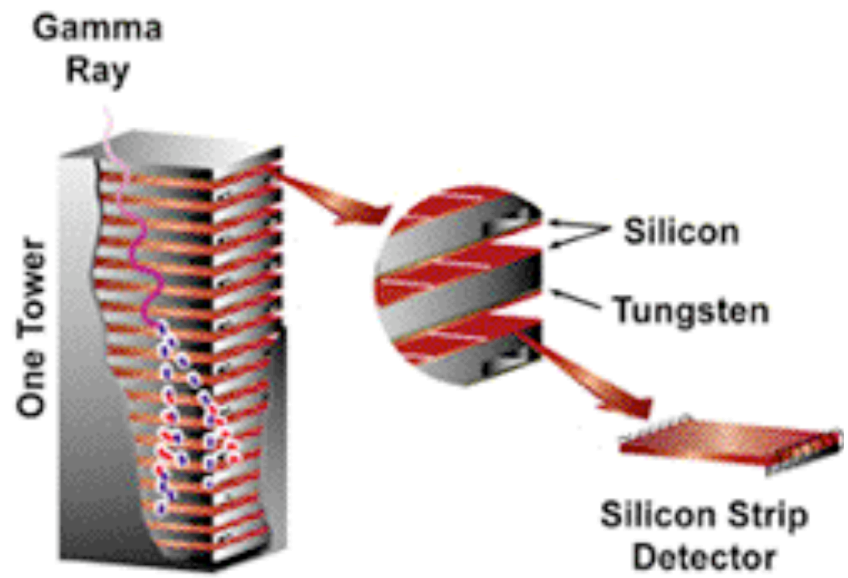


- For each incident gamma ray photon, we want to know its incident direction and energy

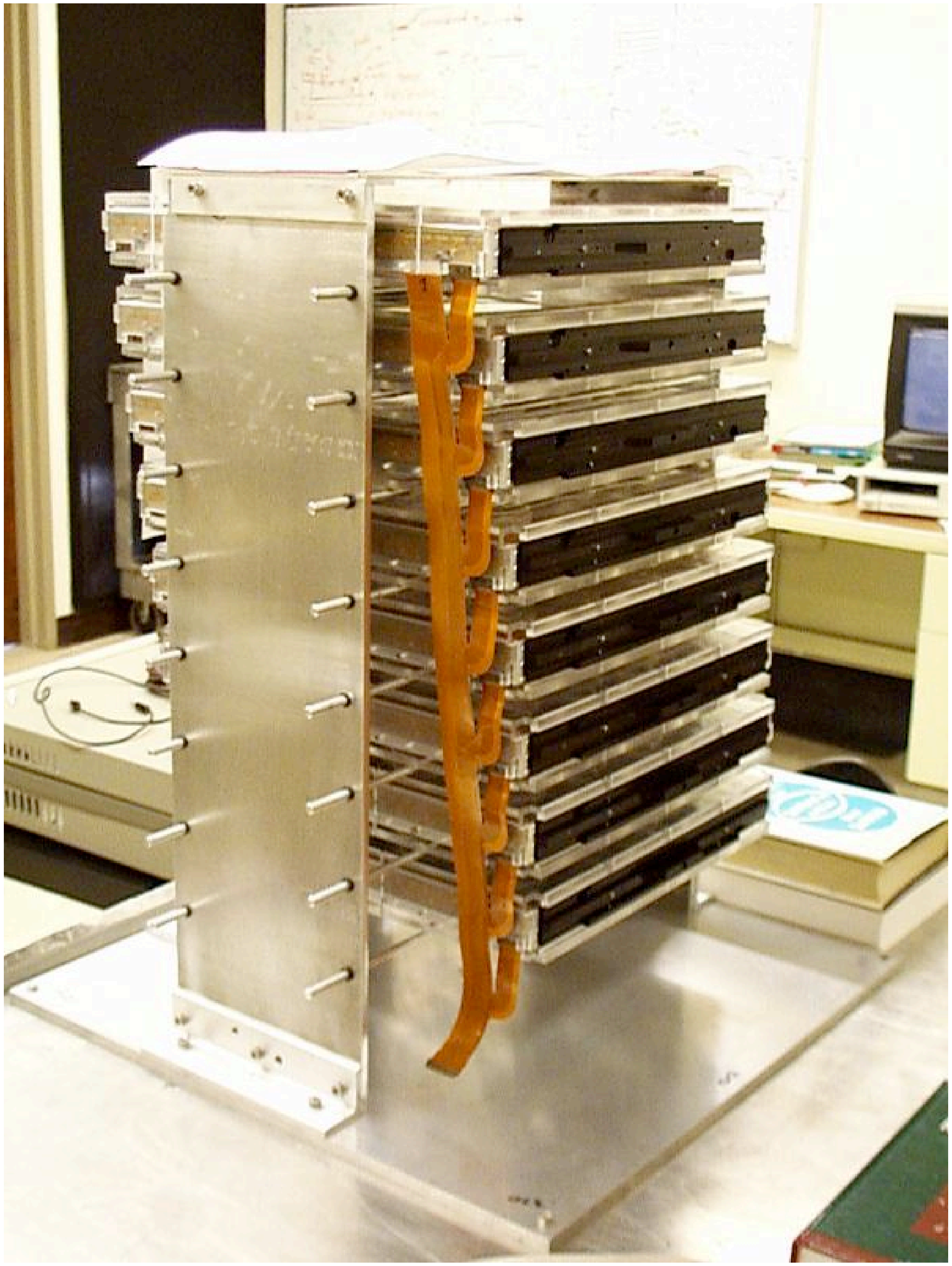
- The LAT has three components:
  - Anticoincidence detector - eliminates responses due to incident charged particles
  - Array of conversion towers - the heart of the detector
  - Imaging calorimeter - measures the residual energy in the particles generated by an incident gamma ray photon

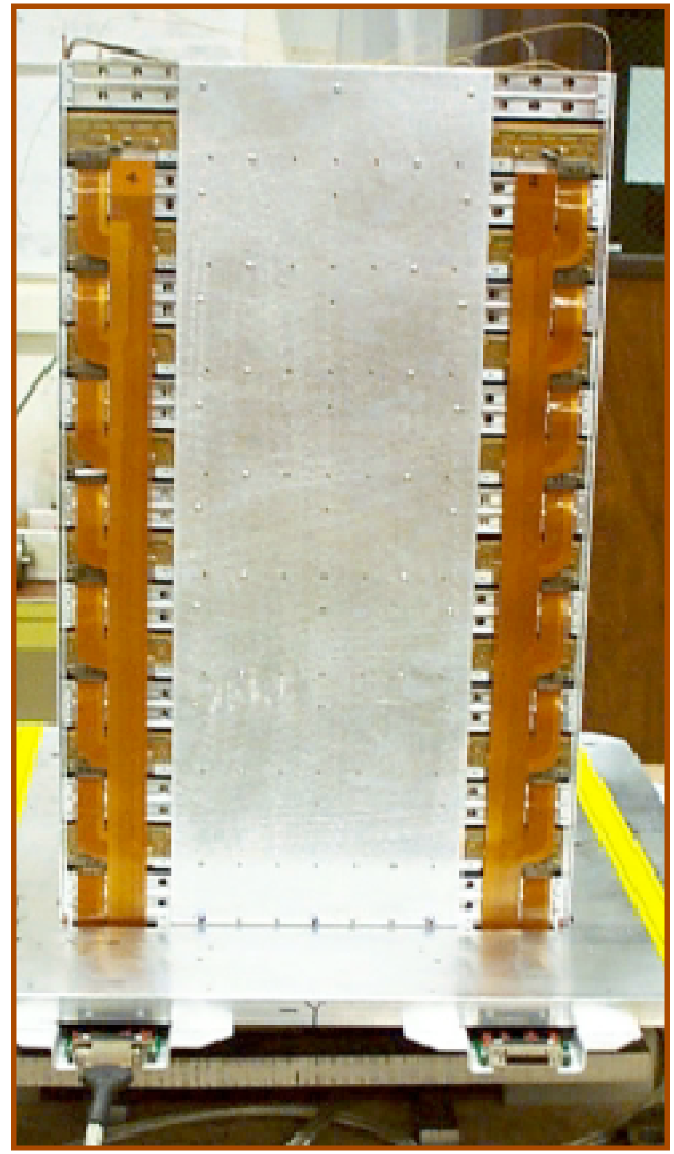
How the conversion towers work

- Alternating conversion and detection layers
- Incident gamma rays are converted into electron/positron pairs
- The electron and positron cascade through the detector
  - Undergo secondary scattering
  - Produce further electrons and photons

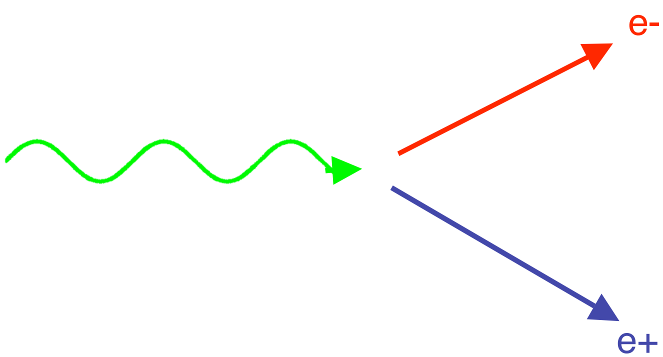


- Each time they cross a detection layer, they trigger the silicon microstrip detectors, producing a readout
- The output from an event is a set of (x,y,z) positions of the silicon microstrips that were triggered (+ calorimeter response)





Physics Processes



Pair production

- conversion of gamma ray photons into electron/positron pairs

multiple coulomb scattering

- charged particles are deflected on interacting with (primarily) atoms

positron anihilation

- positron + electron => photons

ionisation

- liberation of electrons from atoms by the transfer of (at least) the binding energy from a particle to the electron

bremsstrahlung

• radiation emitted by a charged particle undergoing acceleration (typically deceleration when passing through the field of atomic nuclei)

photoelectric effect

• generation of free electrons in a material by incident photons at low energies

compton scattering

• transfer of energy from photons to electrons; may liberate bound electrons

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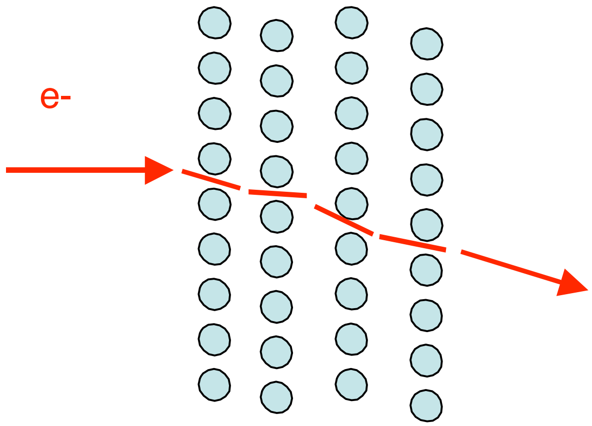

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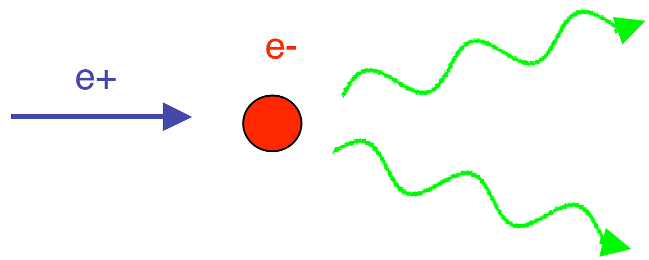

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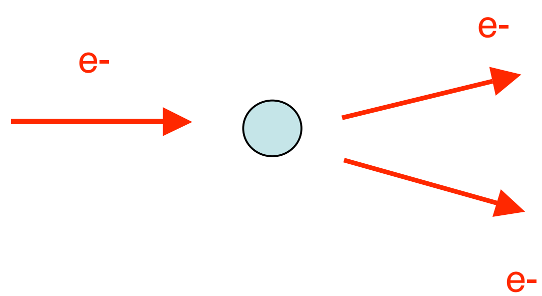

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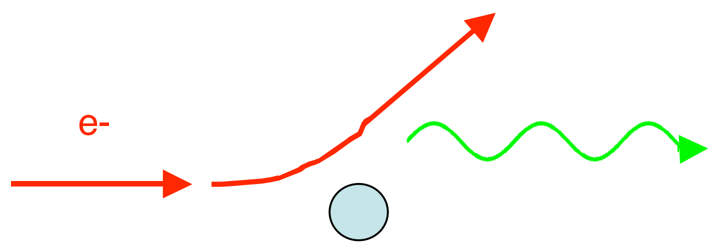

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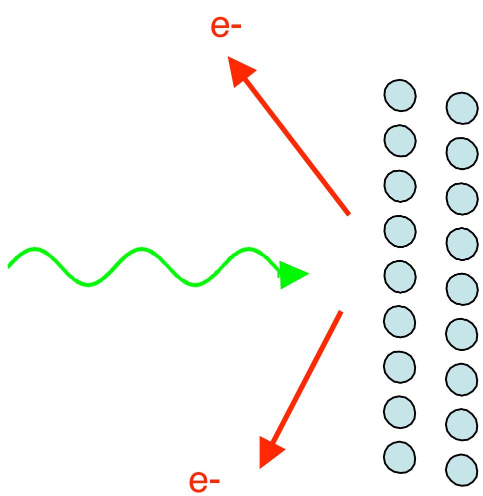

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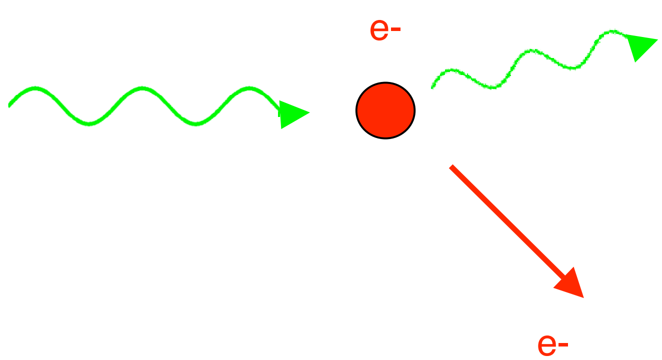

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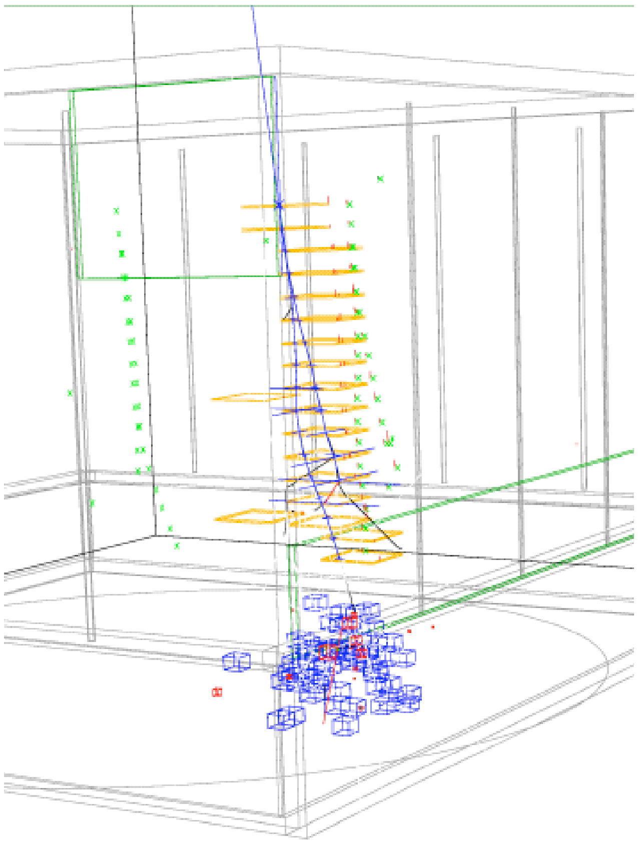
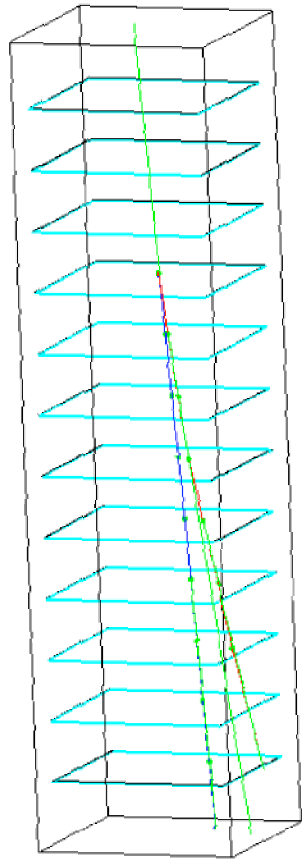
SimpleGLAST



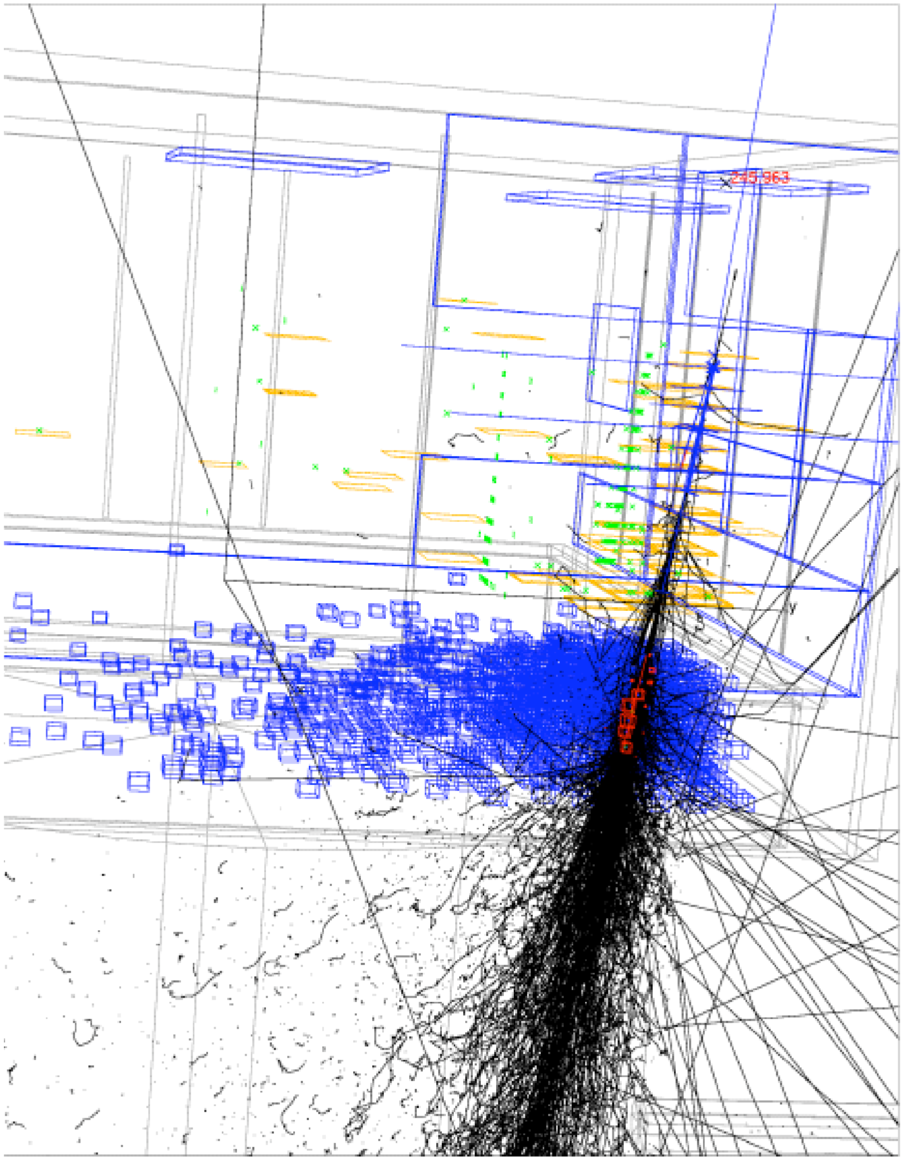


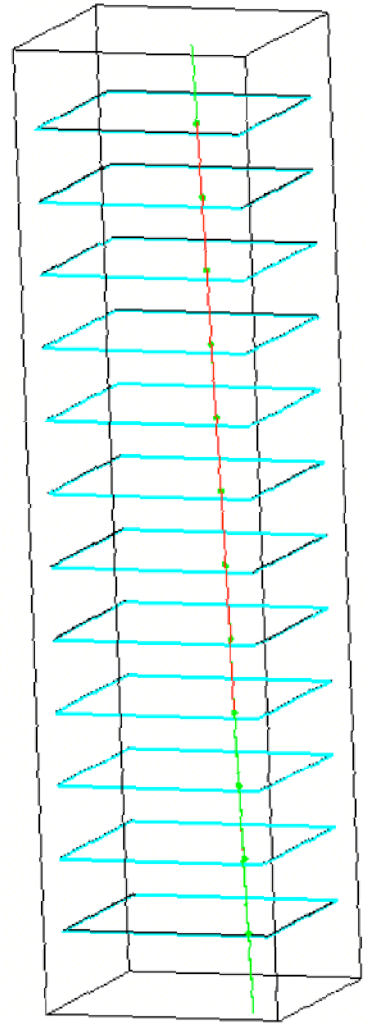
200MeV photon

- **left - GLEAM (GLAST Event Analysis Machine)**
- **right - simplified simulation using Geant4 physics simulation toolkit**

- simplified detector represents one silicon tile in one of the GLAST towers
- has the same conversion geometry (layer spacing, layer thickness)
- the separate x and y detection layers have been merged into one
- low energy physics processes (primarily low energy photons and electrons) have been neglected

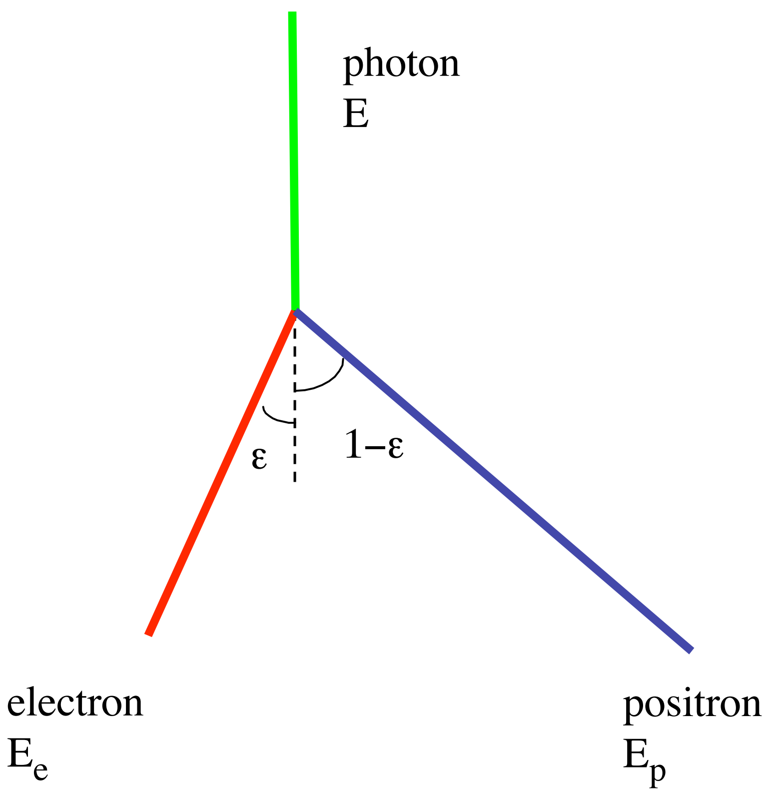
100GeV photon





• At high energy, the start of the track is a straight line; here we concentrate on the more difficult region of low (<1GeV) energy

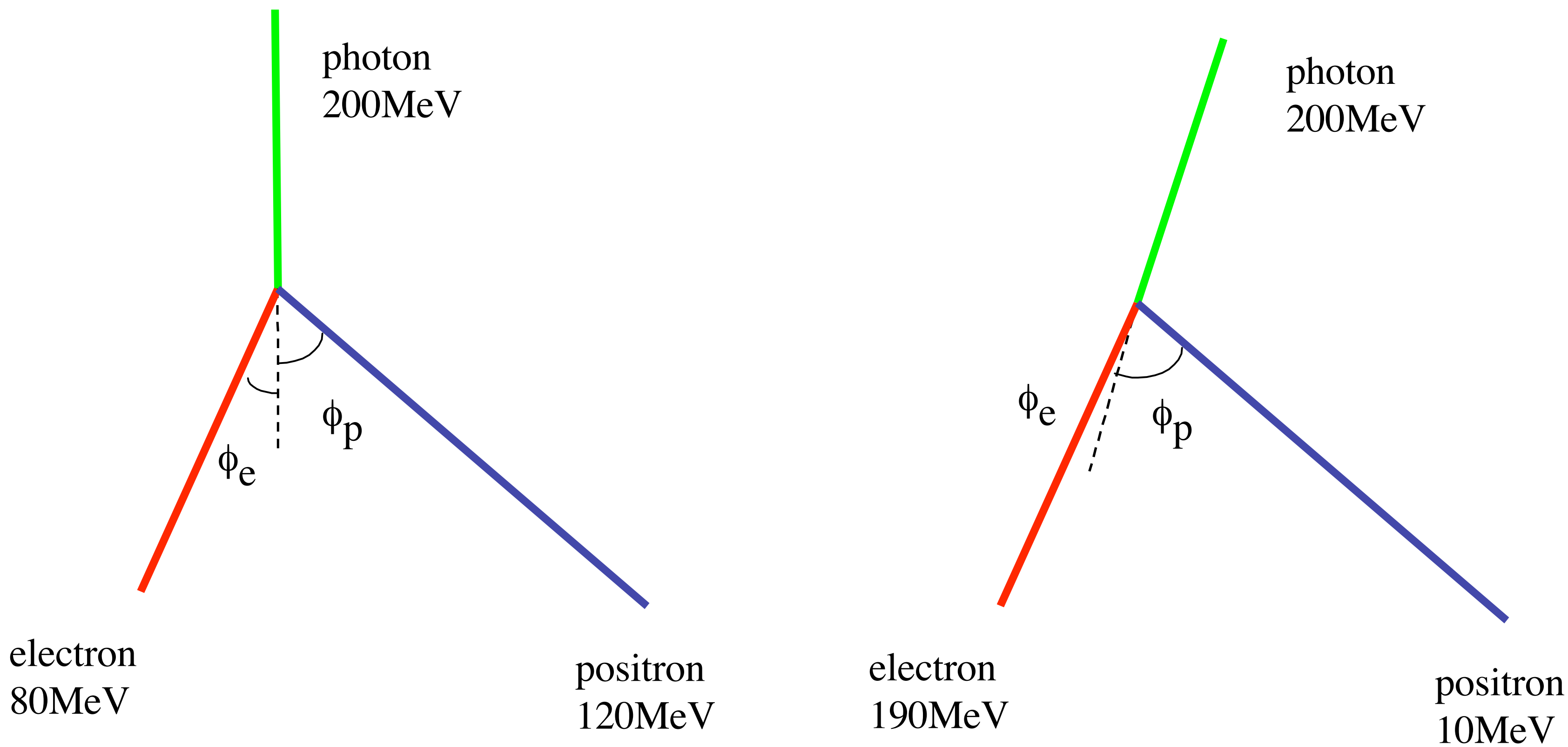
Pair Production - energy and angles



- The trajectories of the electron and positron are determined by the microstrips that fire
- Knowing the energy of the electron and positron is key to determining the direction of the incident photon - the photon direction is determined completely by the trajectories and the energy split.
- The scattering angles are given by

$$\phi_{\pm} = \frac{m_e c^2}{E_{\pm}} u \quad \text{where} \quad E_{+/-} = \varepsilon E$$

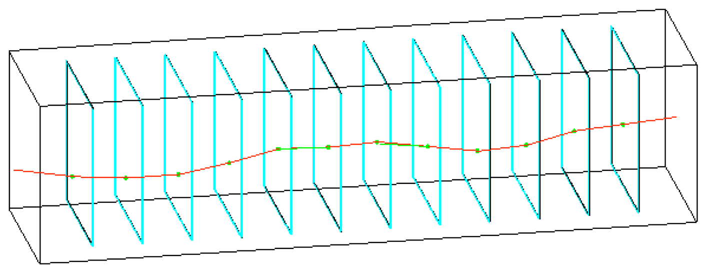
and the distribution of u is given by the physics



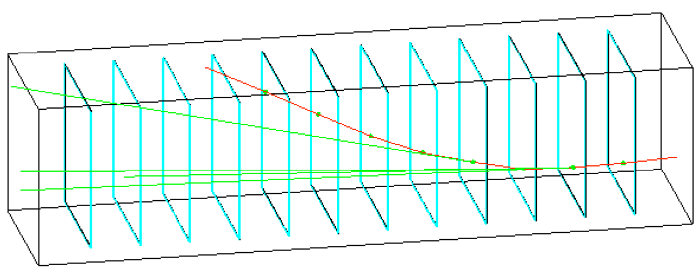
- so to accurately determine the direction of the photon, we need to accurately estimate the energies of the electron and positron

- information about the energies comes from looking at the scattering angles each time the particles traverses a foil

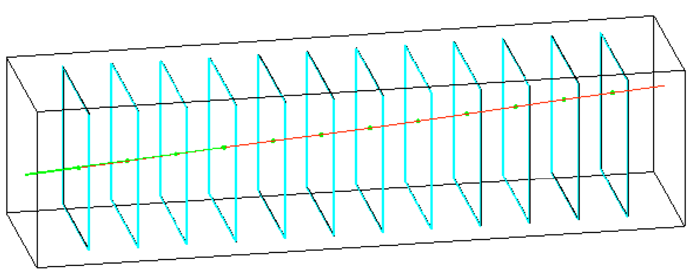
Determining the energy of an electron



20MeV



33MeV



400MeV

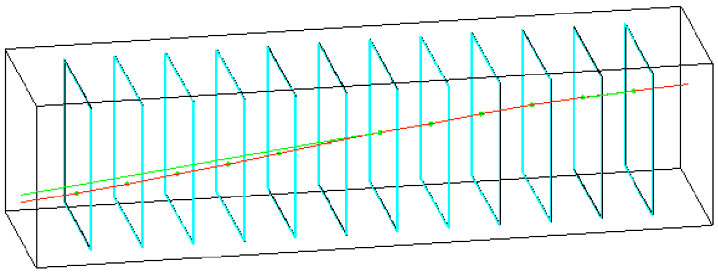
- The central 98% of the scattering distribution is Gaussian
- log(variance) vs log(energy) is a straight line for a fixed geometry
- Estimating the energy is, therefore, roughly the same as estimating the variance of a Gaussian from a set of noisy samples

  (except for energy loss along the trajectory)

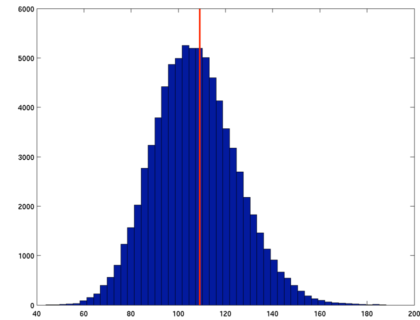
  (noisy samples because of the finite size of the microstrips)
- Apply MCMC to the positions where the electron traverses the conversion layers and the electron's energy

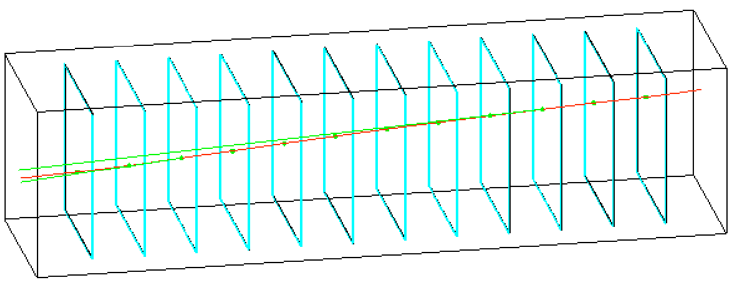
- For simplicity, restricting ourselves to those cases where no secondary charged particles were produced

Determining the energy of an electron (cont)

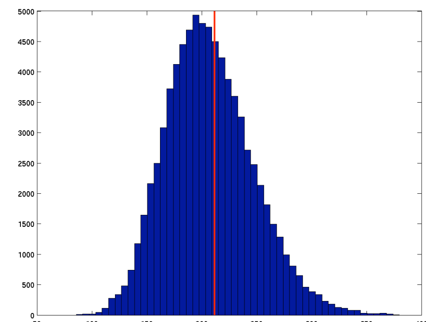


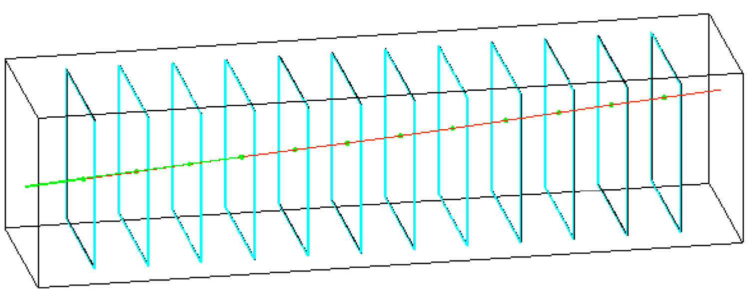
110 MeV



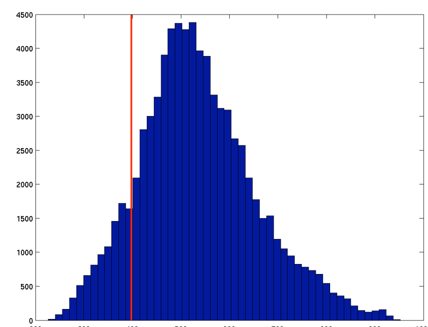


210 MeV





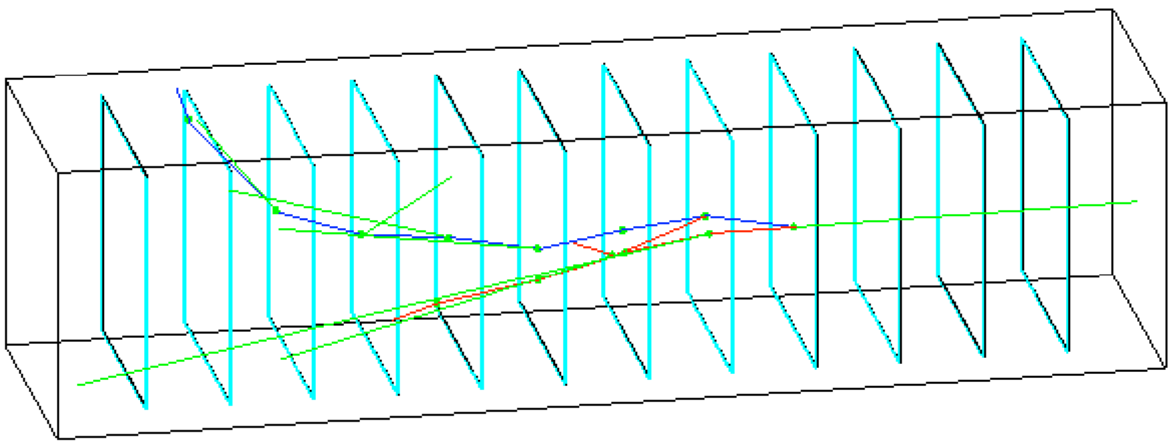
400MeV



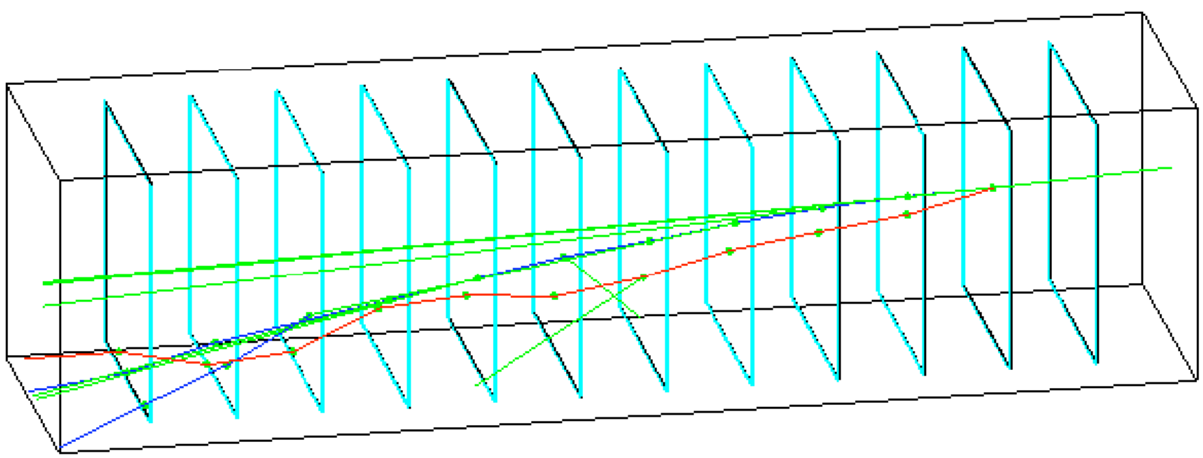
- Some physicists ask why the estimation is “biased”
- Need to show them that “on average” the estimates are correct

Back to Gamma-rays

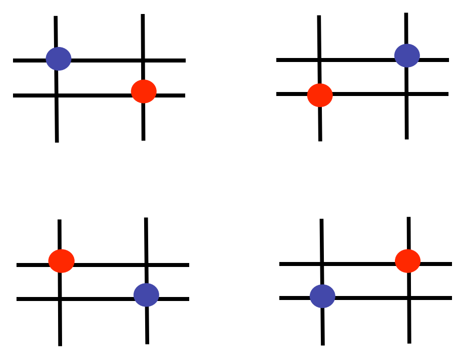
- Gamma-ray events may be somewhat more complex!



The detector tells you at each layer which x-strips fired, and which y-strips fired. There is no way to tell which of the "corners" the particles went through.



So we must also consider the possible permutations of the trajectories

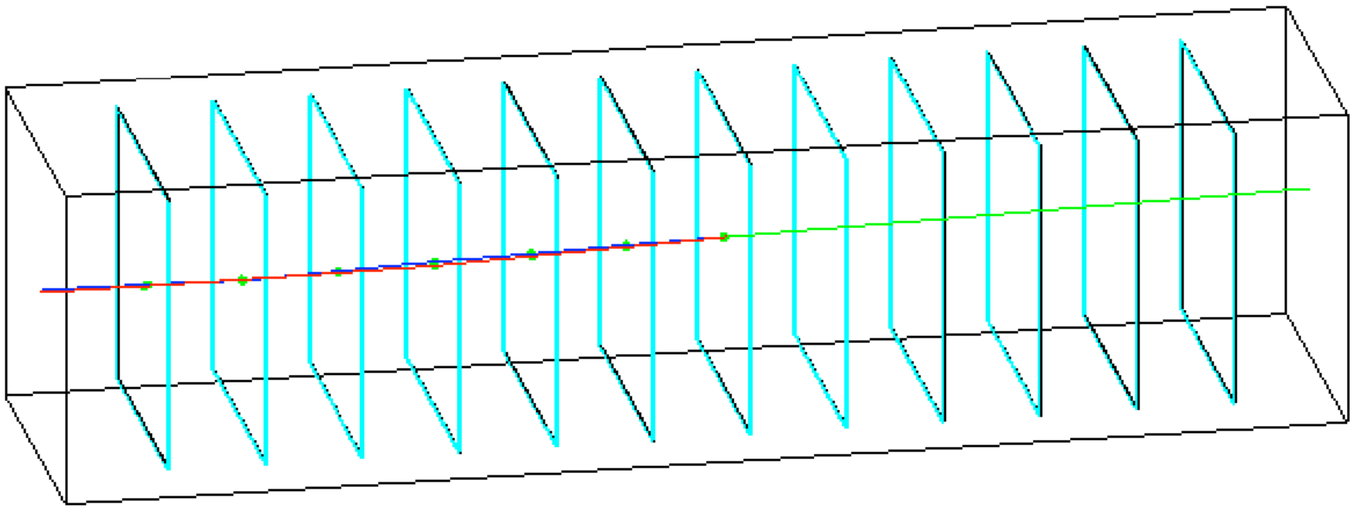


More permutations are possible if secondary charged particles are produced

Computation

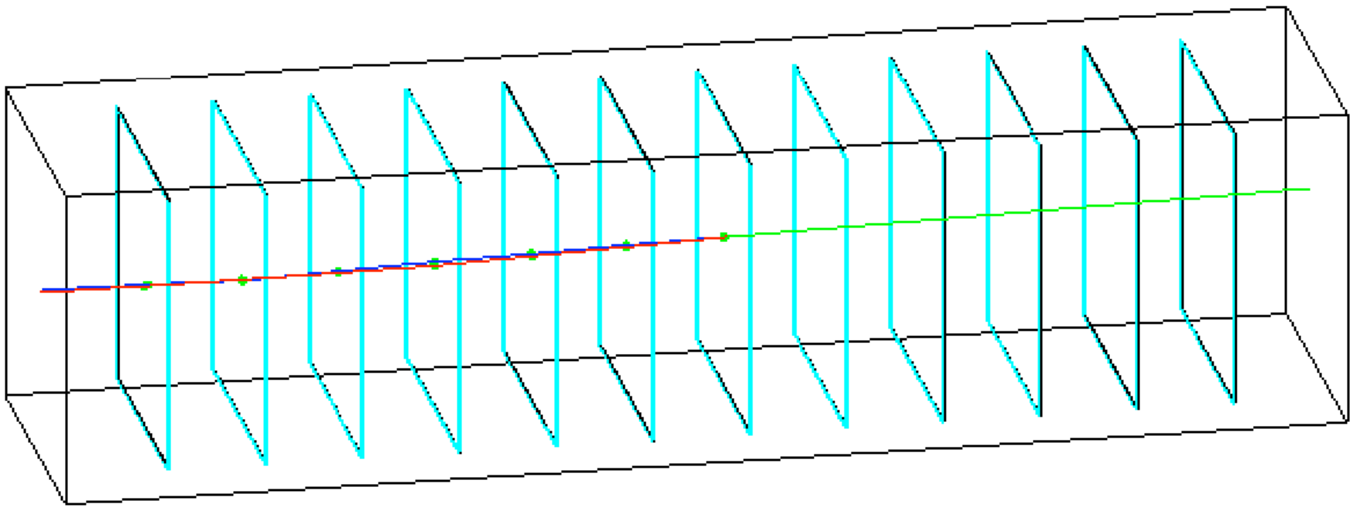
- Combination of Importance Sampling and MCMC:
  - We use Importance Sampling to explore the space of permutations, to put samples into each of the regions of parameter space with appreciable probability
    - need to include the event enery and energy split as well as the geometrical permutations
  - We use MCMC to determine the distribution in each of those regions
    - sample over event energy, energy split, vertex position and the position where the electron and positron traverse each conversion layer

A simple gamma event



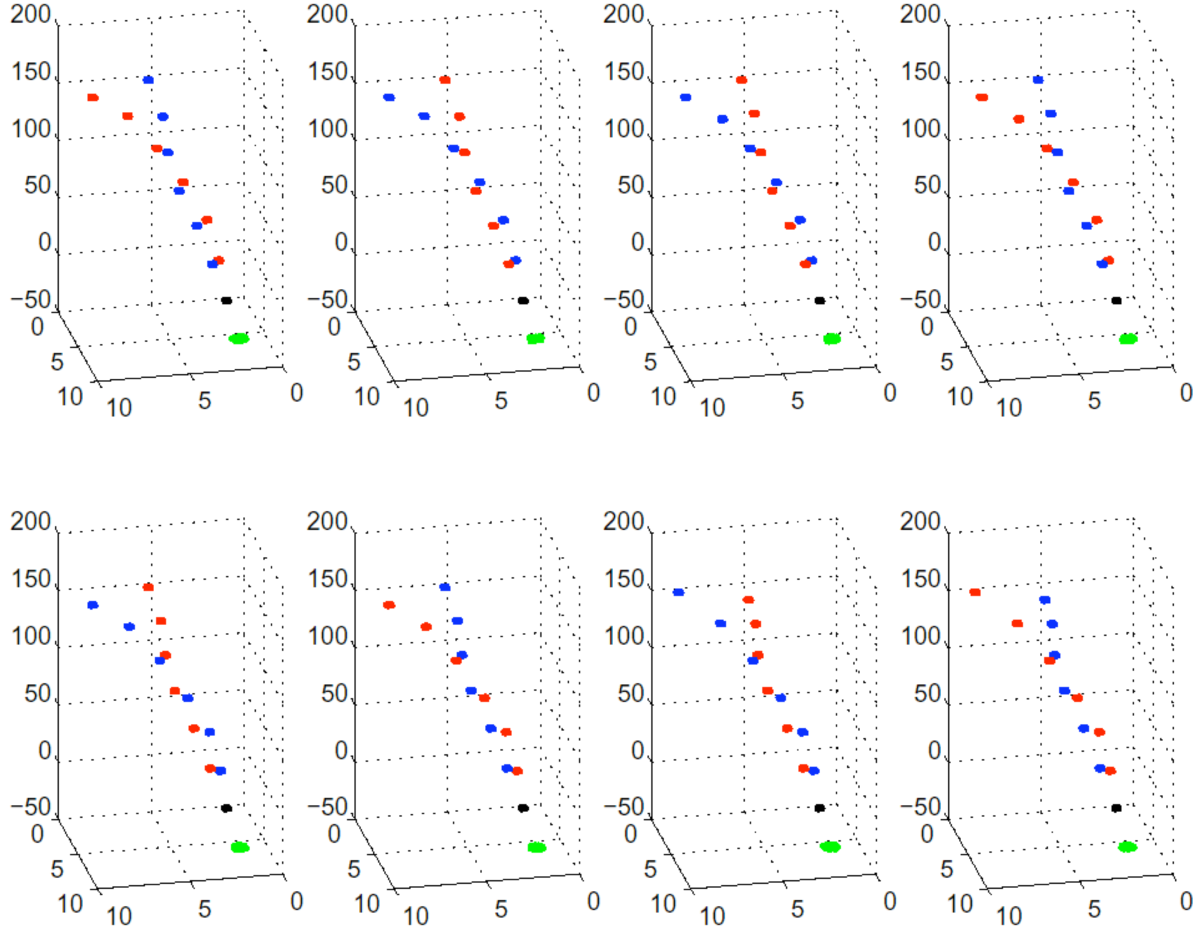
- the trajectories do not diverge too much (small opening angle)
- little energy loss (photon production) along the electron/positron trajectories

A simple gamma event (cont)



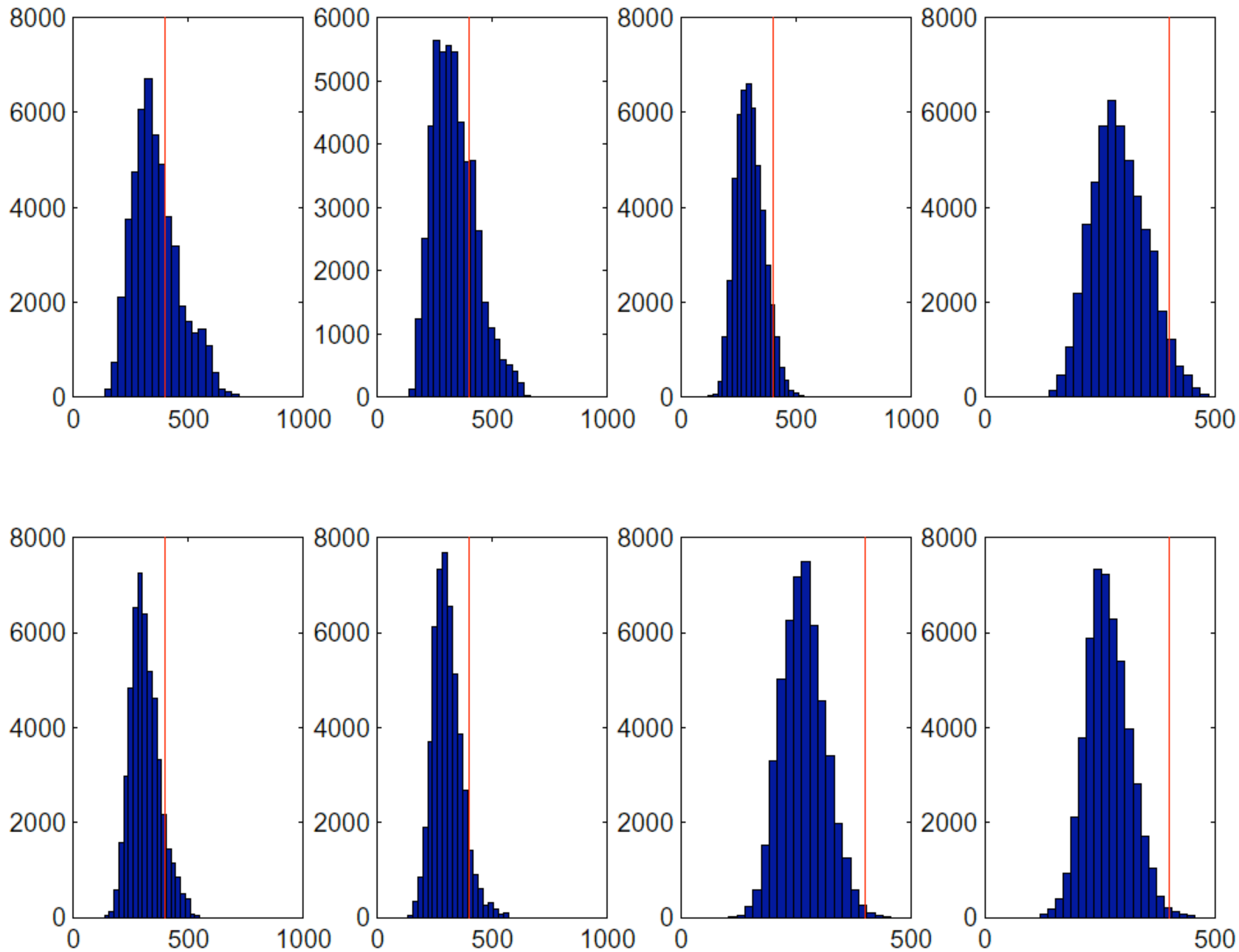
- Recall:
  - explore the geometrical permutations using importance sampling
  - explore the distribution in each region using MCMC

A simple gamma event (cont)



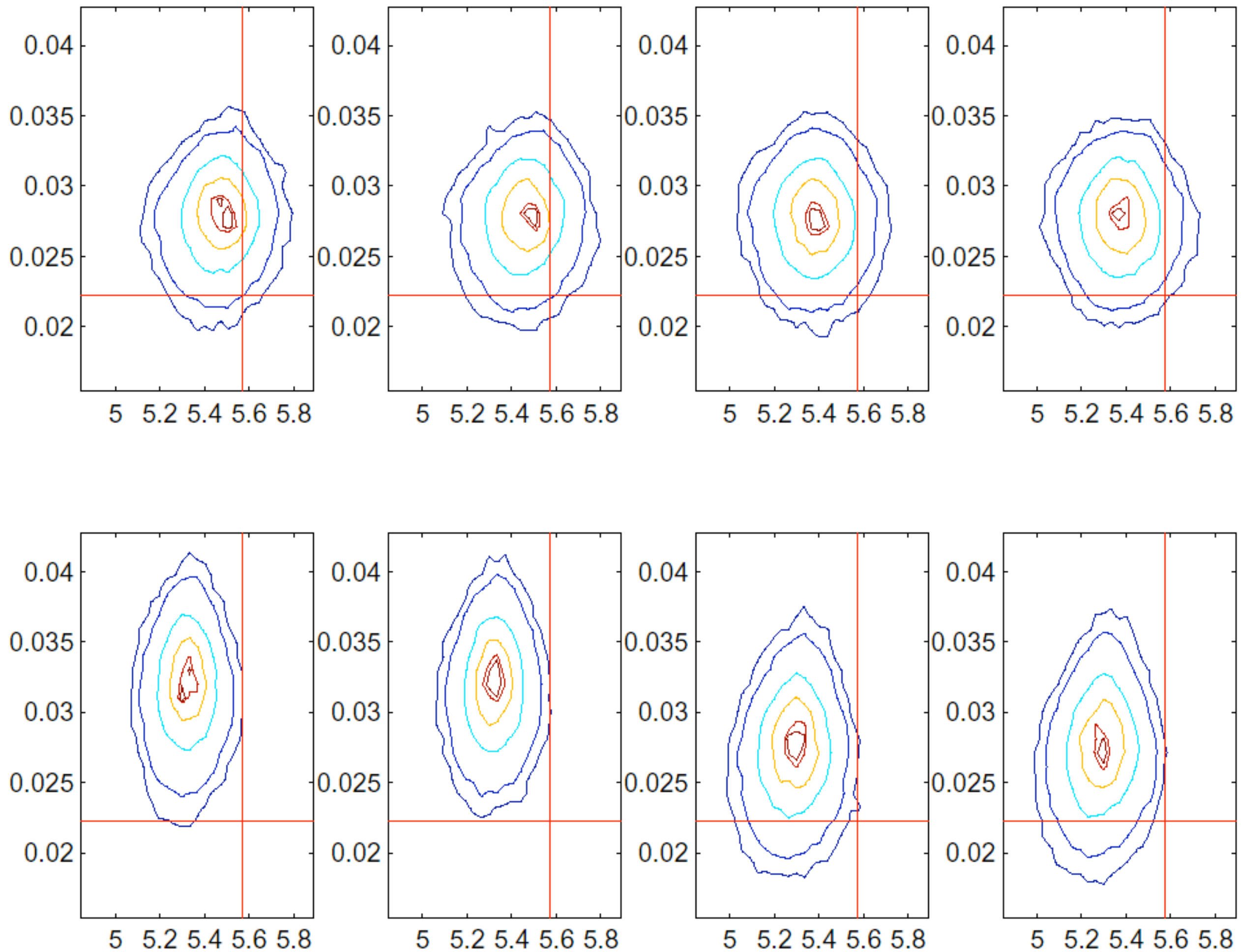
- Eight configurations cover most of the probability mass
  – unless a positron undergoes annihilation, it is impossible to distinguish between the electron and positron, so really only four configurations

A simple gamma event (cont)



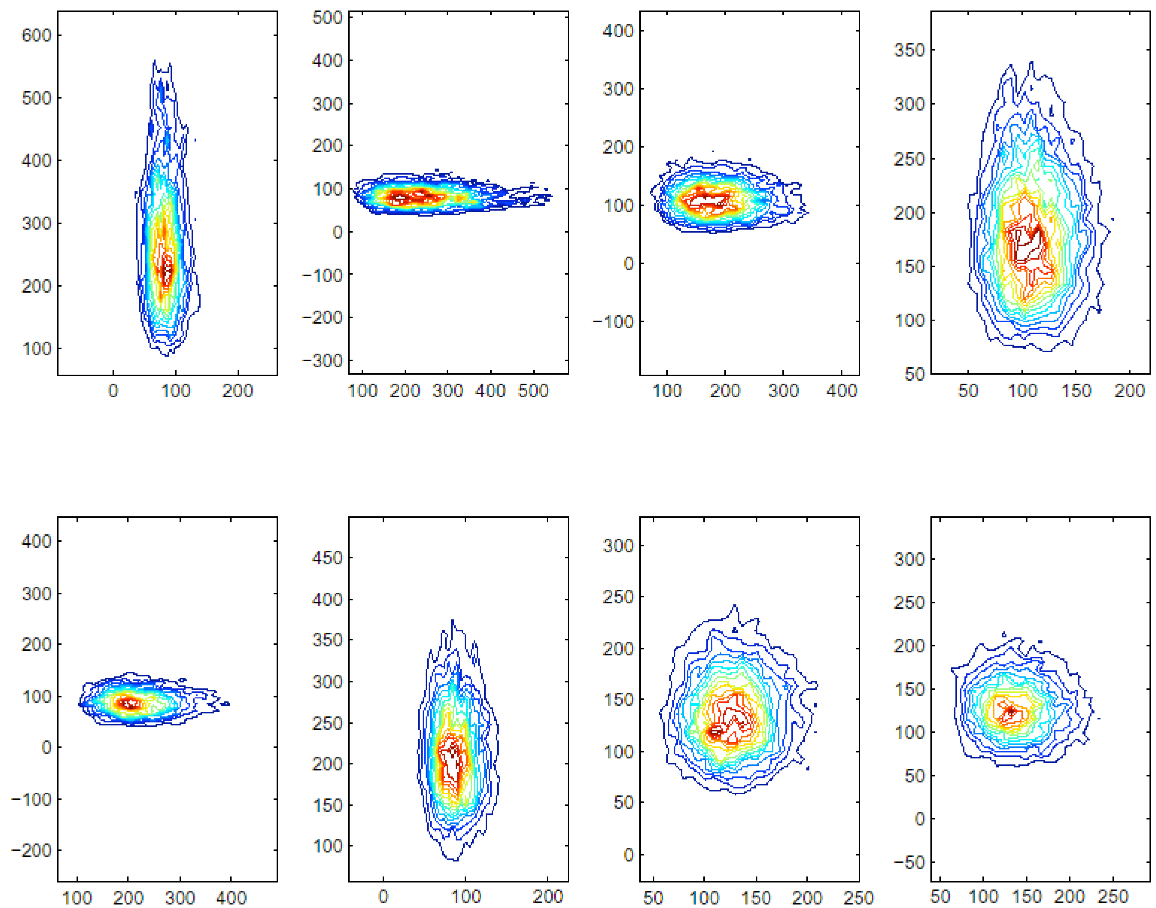
- The energy estimation becomes poorer as the probability of the configuration reduces

A simple gamma event (cont)



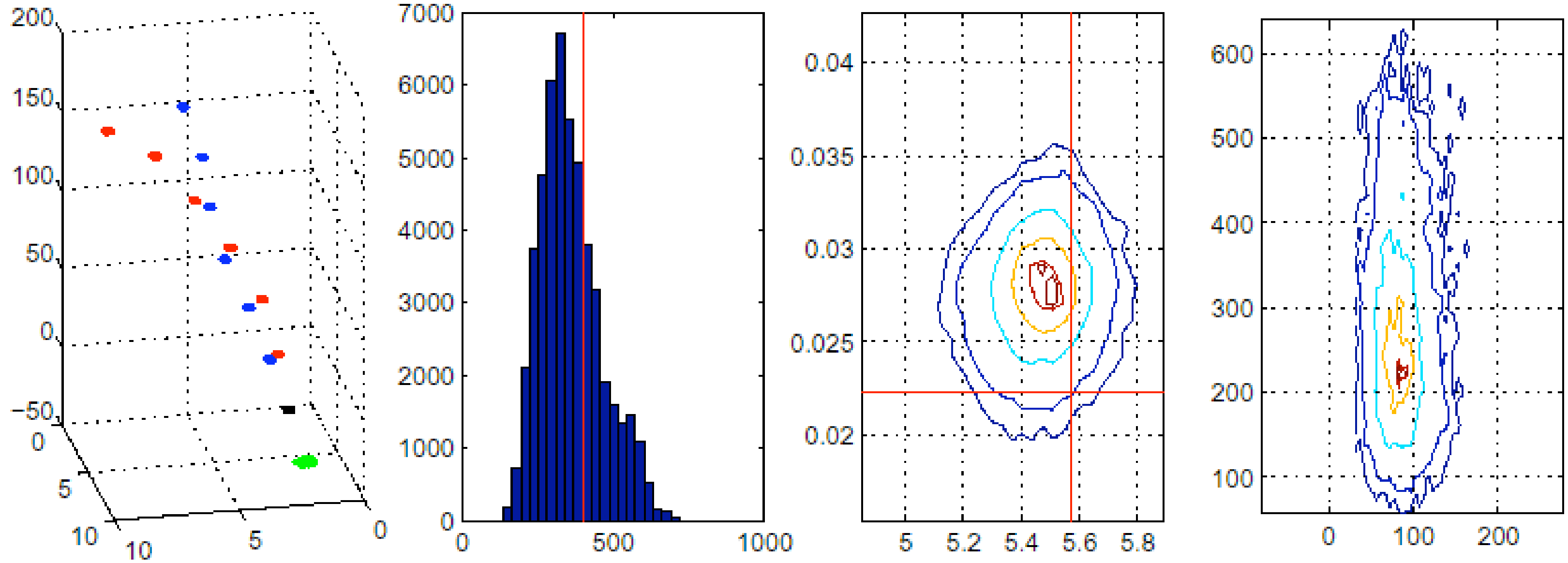
- The true incidence angle is at the 0.05 level of the psf *for this event*
- The angular psf gives a precision of ~0.5° in polar angle (elevation)

A simple gamma event (cont)



- The energy split (x-axis electron; y-axis positron) show symmetry wrt the permutations. True split was 73/326 MeV
  - The underestimate of the higher energy may be due to neglecting the tails of the scattering distributions

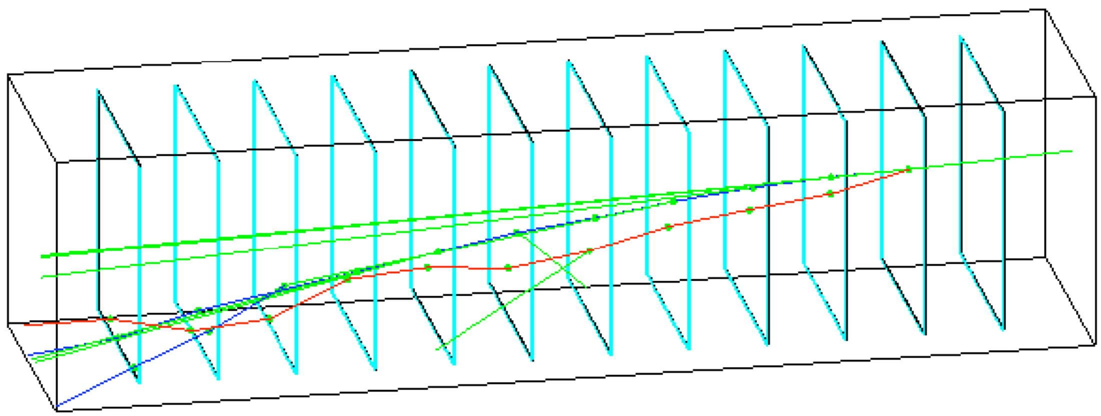
A simple gamma event - summary



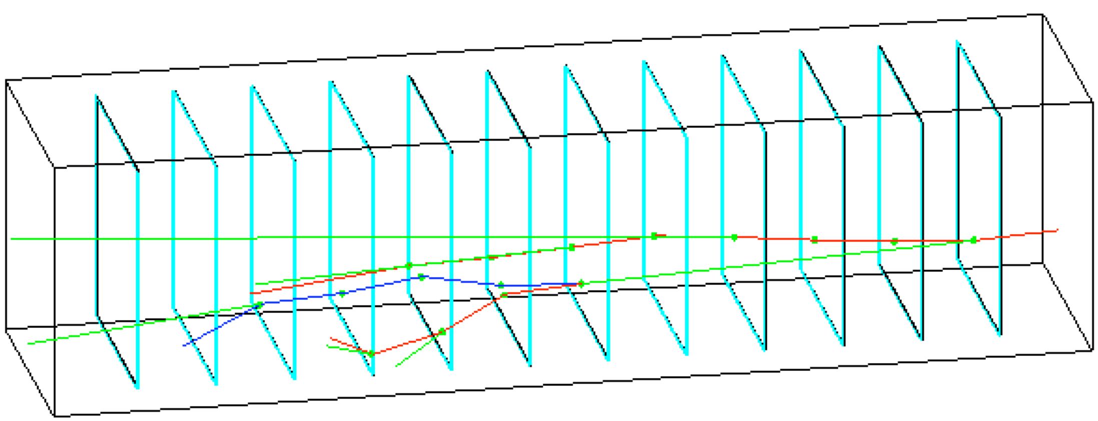
- The best permutation accounts for over 95% of the distribution
- The energy is under-estimated, especially the energy of the high energy particle
- The incidence angles are reasonably well determined

Future work

- Analysis of more complex events



- Multiple secondary charged particles cause the number of geometric permutations to increase rapidly



- Bremsstrahlung on the electron produces a photon. The photon later undergoes pair production.

Future work

- Add more physics:
  - add the tails of the multiple scattering distributions
  - consider the multiple scattering in the layer in which pair production occurs
  - consider the physics processes that occur in the detection layers
  - estimation of the energy loss along the trajectories
  - physics of secondary charged particle production

- Improve the likelihood:
  - a charged particle may fire a “cluster” of microstrips
  - delta rays (low energy electrons) may become trapped in the detection layers and fire very many microstrips
  - it is not yet known if any information about the energy of the particles traversing the microstrips will be available from the detector read-out

Conclusion

"If you have to use statistics, go back and design the experiment properly"

Lord Rutherford

"If you have to use statistics, think about the statistics at the same time as you design the experiment"

Me